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EFFECT OF FUEL AND OXIDANT PARTICLE SIZE ON THE PERFORMANCE CHARACTERISTICS OF 60/40 POTASSIUM PERCHLORATE/ALUMINUM FLASH COMPOSITION

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DOVER, N. J.

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OBJECT

To determine the effect of fuel and oxidant particle size on the performance characteristics of 60/40 potassium perchlorate/aluminum flash composition.

SUMMARY

Sub-sieve potassium perchlorate and atomized aluminum powders, commercially classified into fine, medium and coarse fractions, were blended in 60/40 potassium perchlorate/aluminum compositions, loaded into plastic Titan cartridge cases, and tested for luminosity characteristics at sea level and a simulated altitude of 80,000 feet.

Those systems containing fine (0-12 micron), medium (0-23 micron), and coarse (6-85 micron) potassium perchlorate together with fine aluminum (0-17 micron) were the only systems which emitted enough light for pyrotechnic applications. Maintaining the aluminum particle size constant (fine fraction) and decreasing the oxidant particle size increased efficiency (candleseconds/gram) at both sea level and 80,000 feet. In general, the peak and integral light varied similarly at high altitude. At sea level, however, the composition with the coarse oxidant fraction produced the highest peak and integral light. This finding was attributed to the greater tapped density of the coarse oxidant fraction, resulting in substantially greater sample weight in the Titan cartridge.

It was concluded that, independent of potassium perchlorate size range, use of medium (8.4-40 micron) or coarse (24-62 micron) aluminum degrades the light output to below useable levels. For the particle size ranges considered, use of a fine aluminum fraction is necessary for high order performance.

INTRODUCTION

It has long been known that average particle size and particle size range of ingredients are important parameters in determining the luminosity characteristics of pyrotechnic flash compositions. Unfortunately, since the fuels and oxidants normally used in such compositions are essentially in the sub-sieve range, and since until quite recently no adequate methods were available for classifying these materials into narrow particle size ranges, no definitive study of these parameters was possible.

Among the methods evaluated for separating sub-sieve aluminum and potassium perchlorate into narrow particle size ranges were the Haultain Infrasizer (Ref 1), the Bahco Centrifugal Elutriator[1], the Majac Model L Air Classifier[2] and the

[1] H. W. Dietert Co., Detroit, Michigan.

[2] Majac, Inc, Sharpsburg, Pittsburgh, Pennsylvania.

Buckbee Mears Micromesh Sieves[1]. While a detailed description of these trial classifications is beyond the scope of this report, it can be generally stated that although considerable enrichment of fractions could be obtained utilizing several of the above techniques, the isolation of "clean-cut" fractions showing little or no particle size overlap was not found to be possible within the subsieve range.

The final and most successful classification technique employed involved the use of the Alpine American Mikroplex Spiral Air Classifier[2]. This instrument separates a powder of mixed particle size into two fractions above and below a determined particle size. The separation is effected in a flat, cylindrical classifying chamber through which air flows inward in a spiral path. Any particle carried by this air stream has a centrifugal and a friction drag force imposed upon it that essentially act in opposite directions. Thus, for particles of greater mass, the predominant force is centrifugal and the particles tend to move tangentially away from the air stream. For particles of small mass, the friction drag force predominates, causing a radial movement toward the center of the classifying chamber and the fine particle outlet located there. Changes in the magnitude of the forces applied to the particles entrained in the air stream are made by varying the spiral curvature through a vane assembly, thus changing the particle size range at which separation occurs.

The system chosen for particle size evaluation was a 60/40 potassium perchlorate/aluminum composition, in common use in many pyrotechnic flash items. The aluminum used was spherical atomized material, prepared and classified by the Valley Metallurgical Processing Company, Inc., Essex, Connecticut, using the Alpine American Mikroplex Spiral Air Classifier. The potassium perchlorate used was specification grade (PA-PD-254) material which was classified by the Alpine American Corporation using the above equipment.

Luminosity tests were conducted at sea level and at a simulated altitude of 80,000 feet. The test vehicle employed was a Titan flash cartridge fabricated of cotton-flock-filled, nitrile-rubber-modified phenolic resin (GE 12808) (Fig 6, p 22).

The particle size characteristics of the fine, medium, and coarse aluminum and potassium perchlorate fractions used were determined (Table 1, p 8) by an air permeability method, the Fisher Sub-Sieve Sizer (Ref 2), a sedimentation method based upon Stokes' Law dealing with fall in air (Ref 3), and microscopic examination. A 90% range figure was used for reporting microscopic and sedimentation particle size ranges. This was done by cutting 5% off both tails of each distribution curve.

[1]Buckbee Mears Co., St. Paul, Minnesota.

[2]Alpine American Corp., Saxonville, Massachusetts.

RESULTS

The particle size characteristics of the fine, medium, and coarse aluminum and potassium perchlorate fractions are detailed in Table 1 (p 8).

Average values for the burning parameters obtained at sea level and at 80,000 feet in the Pyrotechnics Laboratory high altitude chamber are compiled in Table 2 (p 9), together with th average weight of composition loaded into the Titan cartridges for each blend. The individual results which were used to obtain the average values in Table 2 are listed in Table 3 (p 10).

Table 4 (p 13) includes tapped density values obtained with the aluminum and potassium perchlorate fractions used in this study. These values were obtained using the Pyrotechnics Laboratory Tapped Density Apparatus (Ref 4). Table 5 (p 14) details the tapped densities of the blended fractions evaluated in this study.

The variations of time to peak light (Fig 1, p 17), peak light (Fig 2, p 18), integral light (Fig 3, p 19), duration of light emission (Fig 4, p 20), and efficiency (Fig 5, p 21) are plotted versus potassium perchlorate average particle size, keeping the aluminum average particle size constant at 5.0 microns.

Figures 7, 8, and 9 (pp 23, 24, and 25) are typical time-intensity curves for the various mixtures at both sea level and a simulated altitude of 80,000 feet.

DISCUSSION OF RESULTS

Light emission varied as the particle size of either ingredient in the 60/40 potassium perchlorate/aluminum composition was changed. An increase in the particle size range of aluminum from 0 - 17.0 microns (fine) to 8.4 - 40.0 microns (medium) or 24.0 - 62.0 microns (coarse) caused a drastic decline in peak intensity, integral light, and efficiency at both sea level and 80,000 feet, regardless of which size potassium perchlorate was used (Table 2). Mixtures containing medium or coarse aluminum fractions produced, at best, extremely poor light emission, and at worst, non-ignition or erratic burning.

Total flash duration declined a minimum of 50% when aluminum fractions other than fine were used (Table 2). Mixtures containing fine aluminum fractions yielded longer times to peak light under sea level conditions (more than 0.8 millisecond; Fig 1), while all other mixtures, including those containing the fine aluminum fraction at 80,000 feet, gave shorter times to peak light (less than 0.8 millisecond).

It was apparent that only 60/40 potassium perchlorate/aluminum compositions containing a fine (0 - 17 microns) aluminum fraction produced sufficient light for practical end-item application. The medium and coarse aluminum fractions in combination with potassium perchlorate did not produce sufficient light to be considered for end-item use. This is probably due to the bursting of the plastic cartridge case before sufficient fuel could be vaporized. The stoichiometric reaction between potassium perchlorate and aluminum (65.8% potassium perchlorate +34.2% aluminum) furnishes sufficient heat (2538 cal/g) to vaporize the remaining aluminum in the 60/40 composition (Tables 6 and 7, pp 15 and 16). However, the effect of aluminum particle size on the rate of this vaporization is not known. It is reasonable to assume that finer particles will vaporize more rapidly than larger particles, and this may well explain why little light is produced with medium and coarse aluminum fractions. The fact that some light was emitted from these systems perhaps indicates that some of the finer particles were vaporized and reacted. The above mechanism occurs before the case bursts.

Luminous efficiency (candleseconds/gram) at both sea level and high altitude increased as the particle size range of the potassium perchlorate decreased when the fine aluminum fraction was used as fuel. This increase in efficiency (1/10 max) was more pronounced at 80,000 feet than at sea level (Fig 5, p 21). The integral and peak light intensities varied similarly to the efficiencies at 80,000 feet, but an opposite trend was noted under sea level conditions when the coarse potassium perchlorate fraction was used (Figs 2, 3, pp 18, 19).

No explanation could be established for variation of flash duration with potassium perchlorate particle size at either high altitude or sea level (Fig 4, p 20).

Identical average times to peak light were obtained at 80,000 feet for systems containing the fine fuel fraction with fine, medium, and coarse oxidant fractions (Fig 1, p 17). At sea level, however, the identical systems showed increasing times to peak light with increasing oxidant size.

The phenomenon that fine/coarse fuel/oxidant fractions should produce greater integral and peak light intensities and a lower overall efficiency at sea level than fine/fine or fine/medium fuel/oxidant mixtures was due to the fact that a far greater weight of composition containing coarse oxidant could be loaded into the Titan cartridge case than could one containing fine or medium oxidant. Compositions containing coarse oxidant were found to have a far greater tapped density than compositions containing the fine oxidant (Table 5, p 14). That the coarse oxidant fraction should pack more densely than either the fine or medium fractions is an anomaly due probably to the observed phenomenon that bulkiness increases with decreasing particle size (Ref 5). This may be the result of the buildup of static electrical charges on the fine particles, which would effectively prevent close packing, and encourage agglomeration in small loosely packed clumps. This clumping effect can be seen with potassium perchlorate and to a lesser extent with aluminum below a presently unknown particle size threshold value (Table 4, p 13).

The time-intensity curves shown in Figures 7, 8, and 9 (pp 23, 24, and 25) were the most representative curves obtained from each group tested at both sea level and the 80,000-foot simulated altitude. The areas under each curve represent the integral light emitted by the system. No direct comparison of areas can be made, however, without the various calibration factors which were used in the testing. A direct comparison of the burning duration can be made, since the millisecond markers on the upper horizontal axis used to time the durations were kept constant throughout the testing. Short burning durations (lower halves of Figs 7, 8, and 9, pp 23, 24, and 25), as indicated by a prompt return to the lower horizontal axis, indicate poor light emission. Conversely, longer burning durations (upper halves of Figs 7, 8, and 9) indicate greater luminosity.

CONCLUSIONS

1. Optimum luminous efficiencies are obtained at both sea level and 80,000 feet with 60/40 potassium perchlorate/aluminum compositions containing a fine (0-17 micron) aluminum fraction. A change to medium (8.4-40 micron) or coarse (24-62 micron) aluminum fractions degrades the light output to below useable levels, regardless of oxidant particle size.

2. Maintaining the aluminum particle size constant (0-17 micron) and decreasing the oxidant particle size produces a trend toward increasing luminous efficiencies at both sea level and high altitude.

3. Because of a marked increase in tapped density of the coarse potassium perchlorate fraction (6-85 micron), compositions containing this fraction in combination with fine aluminum yield maximum peak intensity and integral light values at sea level.

4. It is concluded that, for the particle size ranges considered, the particle size range of the aluminum fraction is the controlling factor in determining composition luminous efficiency. In addition, it is apparent that a fine aluminum fraction must be included in any flash system containing this fuel in order to obtain sufficient light for end-item application.

5. Finally, it is apparent that the 60/40 potassium perchlorate/aluminum flash composition can be specifically formulated to yield optimum peak intensities, time to peak intensities or burning durations, etc., by means of a judicious selection of fuel and/or oxidant particle size ranges. However, it must be realized that no one particle size range system will yield across-the-board optimum operational characteristics. Thus, in order to optimize any one luminosity characteristic, it is generally necessary to sacrifice performance of other characteristics.

EXPERIMENTAL PROCEDURES

Topped Densities

The apparatus used for determining the apparent density of the powdered materials used in this study is composed of a motor-driven revolving cam assembly, an automatic timer, and a sample assembly consisting of a graduated cylinder and a cylinder holder (Ref 4). A clean, dry graduated cylinder is weighed to ±0.1 gram on a trip balance. The graduated cylinder is filled to the 50 cc level with the sample. The cylinder is reweighed to determine the sample weight, stoppered and taped to prevent powder from escaping, and inserted into the apparatus. The apparatus is turned on for 10 minutes by means of an automatic timer. This causes the cam to revolve at a constant rate of about 60 revolutions per minute, raising the graduated cylinder and simultaneously turning it part way around before dropping it. This repeated lifting and dropping jars the sample and causes closer packing of the particles. At the end of 10 minutes, the timer automatically breaks the circuit. The volume of the sample in the graduated cylinder is recorded, and the tapped density is calculated by dividing the weight of sample in the cylinder by this volume.

Blending and Loading

All 60/40 potassium perchlorate/aluminum compositions were blended in accordance with Pyrotechnics Laboratory Sequence of Operations P.A.C.U. No. 5 (September 1957). The compositions were loaded into Titan flash cartridges in accordance with Loading Branch Sequence of Operations T1034-5-26. Each Titan cartridge contained 145 mg of lead azide and 35 mg of lead styphnate in the relay charge. No delay charge was used. The relay cup was secured to the cartridge with Duco cement, while an epoxy resin was used to seal the cover to the cartridge body (Fig 6, p 22).

Testing

The loaded cartridges were tested in the Pyrotechnics Laboratory high-altitude tank, which was evacuated to a 20.8 mm pressure, simulating an altitude of 80,000 feet. Each cartridge was suspended in a horizontal position at the center of the 15-foot-diameter portion of the tank by taping them to a ½-inch-diameter vertical steel rod. The end of the cartridge containing the relay assembly was faced away (180 degrees) from the photocell. The lead azide/lead styphnate relay charge was detonated directly by a 90/10 barium chromate/boron squib. This relay charge, in turn, initiated the flash charge, which ruptured the case, and emitted light. A photocell-oscilloscope combination was used to pick up the light.

Materials

The following materials were used:

Atomized aluminum, spherical, Valley Metallurgical Processing Co., Inc., particle size of fractions as given in Table 1 (p 8).

Potassium perchlorate, Specification PA-PD-254, I. M. Sobin Co., average particle diameter, 24 microns; particle size of fractions as given in Table 1.

Titan charge case loading assembly, Drawing CXP-107583, dated 5 February 1959 (Fig 6, p 22), except that the case and cover are fabricated of cotton-flock-filled, nitrile-rubber-modified phenolic resin (GE 12808).

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1. H. E. T. Haultain, *Trans. Canad. Inst. Mining & Metallurgy*, 40, p. 229 (1937)
2. Cadle, R. D., *Particle Size Determination*, Interscience Publishers, Inc., pp. 240-246 (1955)
3. Bulletins 101 and 1244, Sharples Corp., Bridgeport, Pa.
4. Nieradka, Mary N., *Pyrotechnics Laboratory Handbook of Particle Size Procedures*, Picatinny Arsenal (1956), pp 55-57
5. Dallavalle, J. M., *Micromeritics*, Pitman Publishing Corp., 2nd Ed., p. 144 (1948)

TABLE 1

Particle size characteristics of fine, medium, and coarse aluminum and potassium perchlorate fractions

	Atomized Aluminum			Potassium Perchlorate		
	Fine	Medium	Coarse	Fine	Medium	Coarse
Fisher Sub-Sieve Sizer, average particle size, microns	5.0	14.0	39.0	3.0	11.0	24.0
Microscopic count, geometric mean diameter, microns	4.9	19.0	40.0	<1.8	6.6	12.5
Microscopic count, 90% particle size range, microns	0-17.0	8.4-40.0	24.0-62.0	0-12.0	0-23.0	6.0-85.0
Micromerographic analysis, geometric mean, microns	7.2	37.0	44.0	5.4	12.5	49.0
Micromerographic analysis, 90% particle size range, microns	2.7-14.0	17.0-50.0	20.0-60.0	2.2-9.6	1.7-17.5	4.0-85.0

TABLE 2

Effect of varying ingredient particle size on light characteristics of 60/40 potassium perchlorate/aluminum composition

Particle Size: Potassium Perchlorate	Particle Size: Aluminum	Weight, g	Time to Peak, millisec	Peak Intensity $\times 10^4$ candles	Integral Light $\times 10^3$ candleseconds: 1/10 max	Integral Light $\times 10^3$ candleseconds: Total	Duration, millisec: 1/10 max	Duration, millisec: Total	Efficiency, candleseconds $\times 10^3$ per gram: 1/10 max	Efficiency, candleseconds $\times 10^3$ per gram: Total	No. of Items Evaluated
Sea Level											
F	F	18.2	0.8	28.0	136.4	145.4	10.1	21.7	7.51	8.01	[illegible]
M	F	17.0	1.0	19.8	99.0	104.0	10.6	18.0	5.80	6.10	4
C	F	27.0	3.2	39.4	154.0	164.0	8.6	15.6	5.73	6.06	5
M	M	20.0	0.0	0.3	*	*	*	1.4	*	*	2
F	C	21.0	0.6	0.2	*	0.3	*	9.1	*	0.01	2
C	C	26.9	0.5	2.1	*	*	*	8.0	*	*	2
80,000 feet											
F	F	18.1	0.3	27.7	72.7	75.7	8.9	17.3	4.03	4.19	5
M	F	17.0	0.3	17.0	54.4	59.9	9.7	19.1	3.20	3.52	4
C	F	27.2	0.3	17.0	42.8	48.3	8.0	16.7	1.57	1.74	5
M	M	20.0	0.0	0.2	*	*	*	5.0	*	*	2
F	C	21.7	0.8	0.2	0.2	0.3	3.5	8.0	0.01	0.01	1
C	C	26.7	0.2	1.3	0.9	1.2	1.7	7.5	0.04	0.05	2

Particle Size

	90% Range microns	Average Size, microns	Size Category	Size Code
Potassium Perchlorate	0-12	3	Fine	F
Potassium Perchlorate	0-23	11	Medium	M
Potassium Perchlorate	6-85	24	Coarse	C
Aluminum	0-17	5	Fine	F
Aluminum	8-40	14	Medium	M
Aluminum	24-62	39	Coarse	C

*Could not determine and/or erratic results.

TABLE 3

Individual test values for light characteristics of 60/40 potassium perchlorate/aluminum compositions

Particle Size: Potassium Perchlorate	Particle Size: Aluminum	Weight, g	Time to Peak, millisec	Peak Intensity $\times 10^4$ candles	Integral Light $\times 10^3$ candleseconds: 1/10 max	Integral Light $\times 10^3$ candleseconds: Total	Duration, millisec: 1/10 max	Duration, millisec: Total	Efficiency, candleseconds $\times 10^3$ per gram: 1/10 max	Efficiency, candleseconds $\times 10^3$ per gram: Total	Item No.
					Sea Level						
F	F	16.2	0.8	31.0	152.0	162.0	9.8	19.8	8.13	8.66	1
F	F	17.0	0.8	27.2	136.0	146.0	10.3	25.3	8.00	8.59	2
F	F	17.0	0.8	28.3	129.0	137.0	9.3	20.3	7.59	8.06	3
F	F	18.6	0.5	24.1	115.0	123.0	10.5	23.0	6.18	6.61	4
F	F	19.6	0.8	29.5	150.0	159.0	10.8	20.3	7.65	8.11	5
					80,000 feet						
F	F	17.0	0.3	27.5	62.2	68.0	8.3	14.8	3.66	4.00	6
F	F	17.7	0.3	27.1	76.8	88.2	9.3	20.8	4.34	4.98	7
F	F	19.8	0.3	27.0	70.4	73.3	8.8	18.8	3.56	3.70	8
F	F	17.9	0.3	31.0	86.6	a	9.3	a	4.84	a	9
F	F	18.0	0.3	26.0	67.6	73.3[b]	8.8	14.8	3.76	4.07	10
					Sea Level						
C	F	28.1	3.5	a	161.0	172.0	10.0	20.2	5.73	6.12	11
C	F	26.5	2.8	40.0	185.0	198.0	9.4	17.1	6.98	7.47	12
C	F	27.0	3.5	37.0	167.0	172.0	9.3	13.5	6.19	6.37	13
C	F	26.7	3.5	40.5	157.0	168.0	8.9	17.5	5.88	6.29	14
C	F	26.7	2.5	40.0	103.0	108.0	5.4	9.5	3.86	4.05	15
					80,000 feet						
C	F	27.5	0.3	17.8	42.7	44.9	7.3	10.8	1.55	1.65	16
C	F	27.3	0.3	16.3	44.0	47.7	8.3	13.3	1.61	1.75	17
C	F	27.2	0.3	16.0	39.6	44.2	8.3	17.8	1.46	1.63	18
C	F	26.7	0.3	17.0	41.7	47.2	7.8	19.3	1.56	1.77	19
C	F	27.4	0.3	18.0	46.1	52.5	8.3	22.3	1.68	1.92	20

[a] Values off scale.

[b] Estimated value.

TABLE 3 (cont)

Particle Size: Potassium Perchlorate	Particle Size: Aluminum	Weight, g	Time to Peak, millisec	Peak Intensity $\times 10^4$ candles	Integral Light $\times 10^3$ candleseconds: 1/10 max	Integral Light $\times 10^3$ candleseconds: Total	Duration, millisec: 1/10 max	Duration, millisec: Total	Efficiency, candleseconds $\times 10^3$ per gram: 1/10 max	Efficiency, candleseconds $\times 10^3$ per gram: Total	Item No.
					Sea Level						
C	C	26.7	b	b	b	b	b	b	b	C	21
C	C	26.9	0.2	1.1	0.7	0.8	1.2	7.2	0.03	0.03	22
C	C	27.0			Missed because of delay malfunction						
C	C	27.5	a	a	a	a	-	32.8	a	a	24
C	C	26.8	0.8	3.1	a	5.1	a	9.0	a	0.19	28
					80,000 feet						
C	C	27.2	0.2	0.4	b	b	-	1.2	b	C	25
C	C	26.8	0.2	3.5	b	b	-	2.0	b	C	26
C	C	26.9	0.2	0.5	b	b	-	-	-	-	27
C	C	27.1	0.2	0.7	0.5	0.6	1.2	7.7	0.02	0.02	29
C	C	26.2	0.2	1.5	1.4	1.8	2.2	7.2	0.05	0.07	30
					Sea Level						
F	C	20.4	0.5	0.1	b	0.2	-	10.5	b	0.01	31
F	C	21.9	b	b	b	b	-	-	b	C	32
F	C	[illegible]	b	b	b	b	-	-	b	C	33
F	C	21.7	0.7	0.2	b	0.3	-	7.7	b	0.01	34
F	C	21.3	b	b	b	b	-	-	b	C	35
					80,000 feet						
F	C	22.1	b	b	b	b	-	-	b	C	36
F	C	22.1	b	b	b	b	-	-	b	C	37
F	C	22.2	b	b	b	b	-	-	b	C	38
F	C	21.4	b	b	b	b	-	-	b	C	39
F	C	21.7	0.8	0.2	0.2	0.3	3.5	8.0	0.01	0.01	40

[a] Values off scale.
[b] Values too low to measure.

TABLE 3 (cont)

Particle Size: Potassium Perchlorate	Particle Size: Aluminum	Weight, g	Time to Peak, millisec	Peak Intensity $\times 10^6$ candles	Integral Light $\times 10^3$ candleseconds: 1/10 max	Integral Light $\times 10^3$ candleseconds: Total	Duration, millisec: 1/10 max	Duration, millisec: Total	Efficiency, candleseconds $\times 10^3$ per gram: 1/10 max	Efficiency, candleseconds $\times 10^3$ per gram: Total	Item No.
					Sea Level						
M	F	17.0	1.0	19.50	95.2	99.8	10.5	17.0	5.60	5.87	42
M	F	17.0	1.0	a	a	a	-	21.5	a	a	44
M	F	17.0	1.0	19.50	57.6	102.0	11.0	18.5	5.74	6.00	46
M	F	17.0	1.0	20.40	102.0	107.0	10.5	17.5	6.00	6.29	48
M	F	17.0	1.0	19.80	101.0	106.0	10.5	19.0	5.94	6.24	50
					80,000 feet						
M	F	17.0	0.3	17.40	54.3	59.4	9.8	18.8	3.19	3.49	41
M	F	17.0	0.3	16.70	54.1	59.5	9.8	18.8	3.18	3.50	43
M	F	17.0	0.3	17.10	53.9	59.5	9.3	18.3	3.17	3.50	45
M	F	17.0	Missed because of delay malfunction								
M	F	17.0	0.3	17.00	55.2	61.0	9.8	20.3	3.25	3.59	49
					Sea Level						
M	M	20.0	0.0	0.40	b	b	-	1.8	b	b	52
M	M	20.0	0.0	0.27	b	b	-	1.0	b	b	54
					80,000 feet						
M	M	20.0	0.0	b	b	b	-	-	-	-	51
M	M	20.0	0.0	0.31	b	b	-	2.0	b	b	53
M	M	20.0	0.0	0.14	b	b	-	8.5	b	b	55

[a]Values off scale.
[b]Values too low to measure.

TABLE 4

Tapped density of aluminum and potassium perchlorate fractions

Ingredient	Size Code	Particle Size: 90% Particle Size Range, microns (Microscopic Count)	Particle Size: Average, microns (Fisher Sub-Sieve Sizer)	Tapped Density, g/cc
Aluminum	F	0-17.0	5	1.38
	M	8.4-40.0	14	1.63
	C	24.0-62.0	39	1.68
Potassium Perchlorate	F	0-12.0	3	1.00
	M	0-23.0	11	1.12
	C	6.0-85.0	24	1.52

TABLE 5

Tapped density of 60/40 potassium perchlorate/aluminum compositions containing specified parti 'e size fractions

Potassium Perchlorate Particle Size			Aluminum Particle Size			
Size Code	90% Particle Size Range, microns (Microscopic Count)	Average, microns (Fisher Sub-Sieve Sizer)	Size Code	90% Particle Size Range, microns (Microscopic Count)	Average, microns (Fisher Sub-Sieve Sizer)	Tapped Density, g/cc
F	0-12.0	3.0	F	0-17.0	5.0	0.85
M	0-23.0	11.0	F	0-17.0	5.0	1.23
C	6.0-85.0	24.0	F	0-17.0	5.0	1.56
F	0-12.0	3.0	C	24.0-62.0	39.0	0.98
M	0-23.0	11.0	M	8.4-40.0	14.0	1.34
C	6.0-85.0	24.0	C	24.0-62.0	39.0	1.62

TABLE 6

Pyrotechnics Laboratory thermochemical calculation sheet

No. 101

Ingredients	%	Mol Wt	$\Delta H_{f\,298°K}$	$\Delta F_{298°K}$	Density g/ml
Aluminum (s)	34.2	26.97	0	0	2.70
Potassium perchlorate (s)	65.8	138.55	103.6	72.7	2.524
Products					
Al_2O_3 (s)	64.6	101.94	400.2	378.0	4.00
KCl (s)	35.4	74.56	104.2	97.7	1.99

Reaction: $8\ Al + 3\ KClO_4 \rightarrow 4\ Al_2O_3 + 3\ KCl$

Stoich: $8\ (27) + 3\ (138.6) \rightarrow 4\ (101.94) + 3\ (74.56)$

ΔH_R $8\ (0) + 3\ (103.6) \rightarrow 4\ (400.2) + 3\ (104.2)$

ΔH_F $8\ (0) + 3\ (72.7) \rightarrow 4\ (378.0) + 3\ (97.7)$

Reactants, wt, g 631.8 Theoretical density, g/ml (calc) 2.57

ΔH_r, Kcal, (calc) 1602.6 ΔH_r, cal/g (calc) 2538.0 ΔH_r, cal/ml (calc) 6515

ΔF_r, Kcal, (calc) 1587.0 ΔF_r, cal/g (calc) 2507.0 ΔF_r, cal/ml (calc) 6443

Adiabatic temperature, °K (calc) 3800 Gas volume at 298°K, liters 0

Equivalents:

1 g Al = 1.926 g $KClO_4$ = 7410 cal/g

1 g $KClO_4$ = 0.520 g Al = 3852 cal/g

Theoretical maximum composition Al = 55.5% $KClO_4$ = 44.5%

Ref: JANAF Interim Thermochemical Table
Dow Chemical Co., Midland, Michigan

Computed: G. Weingarten
Checked: S. M. Kaye

TABLE 7

Pyrotechnics Laboratory thermochemical calculation sheet

No. 100

Ingredients	%	Mol Wt	Mols	$\Delta H_{f\,298°K}$	$\Delta F_{298°K}$	Density g/ml
Aluminum (s)	40	26.97	.0148	0	0	2.70
Potassium perchlorate (s)	60	138.55	.0043	103.6	72.7	2.524
Products						
Al_2O_3 (s)	58.1	101.94	.0057	400.2	378.0	4.00
KCl (s)	32.0	74.56	.0043	104.2	97.7	1.99
Al (s)	9.2	26.98	.0034	0	0	2.70

Reaction: $.0148\ Al + .0043\ KClO_4 \rightarrow .0057\ Al_2O_3 + .0043\ KCl + .0034\ Al$

Stoich: $(.0148)(27) + .0043\ (138.55) \rightarrow .0057\ (101.94) + .0043\ (74.56) + .0034\ (27)$

ΔH_R $.0148\ (0) + .0043\ (103.6) \rightarrow .0057\ (400.2) + .0043\ (104.2) + .0034\ (0)$

Reactants, wt, g, 1.00 Theoretical density, g/ml (calc) 2.624

ΔH_r, Kcal (calc) 2.2837 ΔH_r, cal/g (calc) 2284 ΔH_r, cal/ml (calc) 6000

Adiabatic temperature, °K (calc) 3800 Gas volume at 298°K, liters 0

Equivalents:

1 g Al = 1.5 g $KClO_4$ = 5710 cal

1 g $KClO_4$ = 0.667 g Al = 3810 cal

Ref: JANAF Interim Thermochemical Table
Dow Chemical Co., Midland, Michigan

Computed: G. Weingarten
Checked: S. M. Kaye

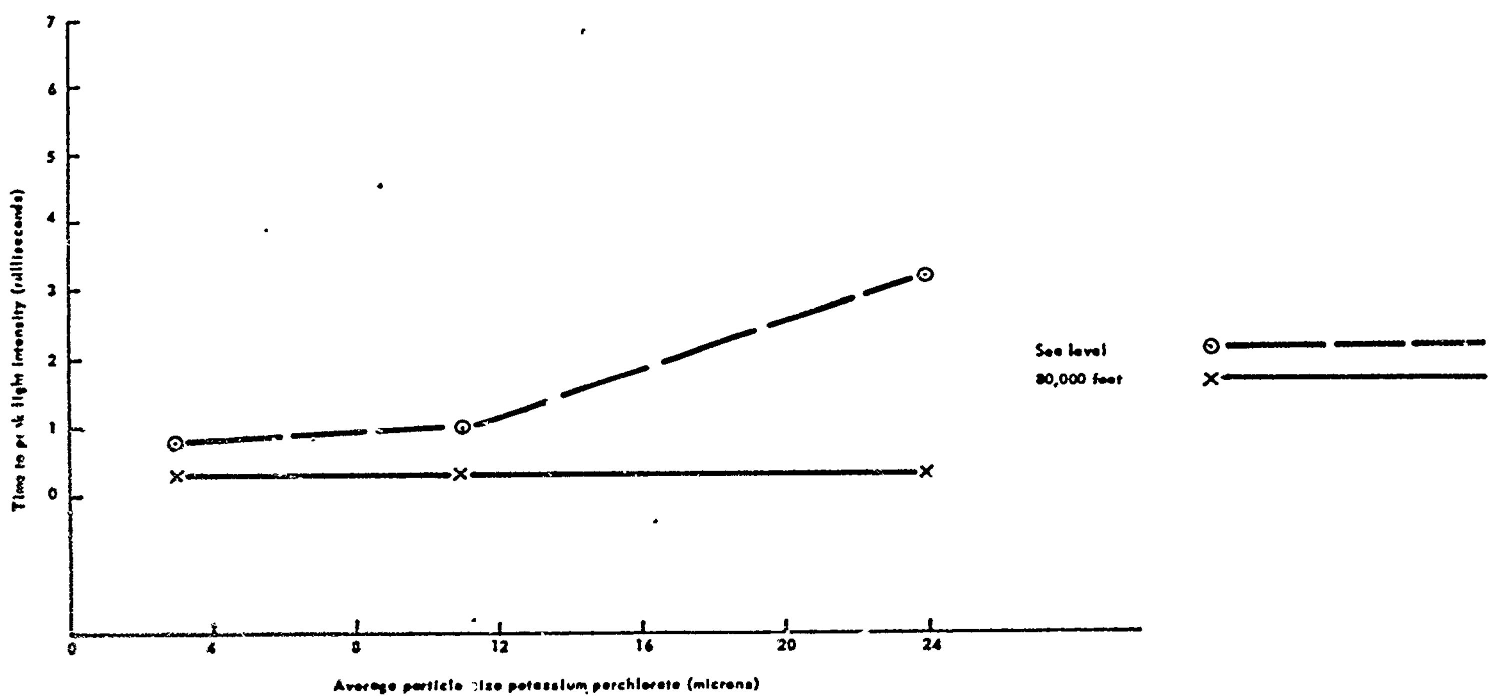

Fig 1 Effect of particle size of potassium perchlorate on time to peak light of 60/40 potassium perchlorate/aluminum compositions (average aluminum particle size: 5.0 microns)

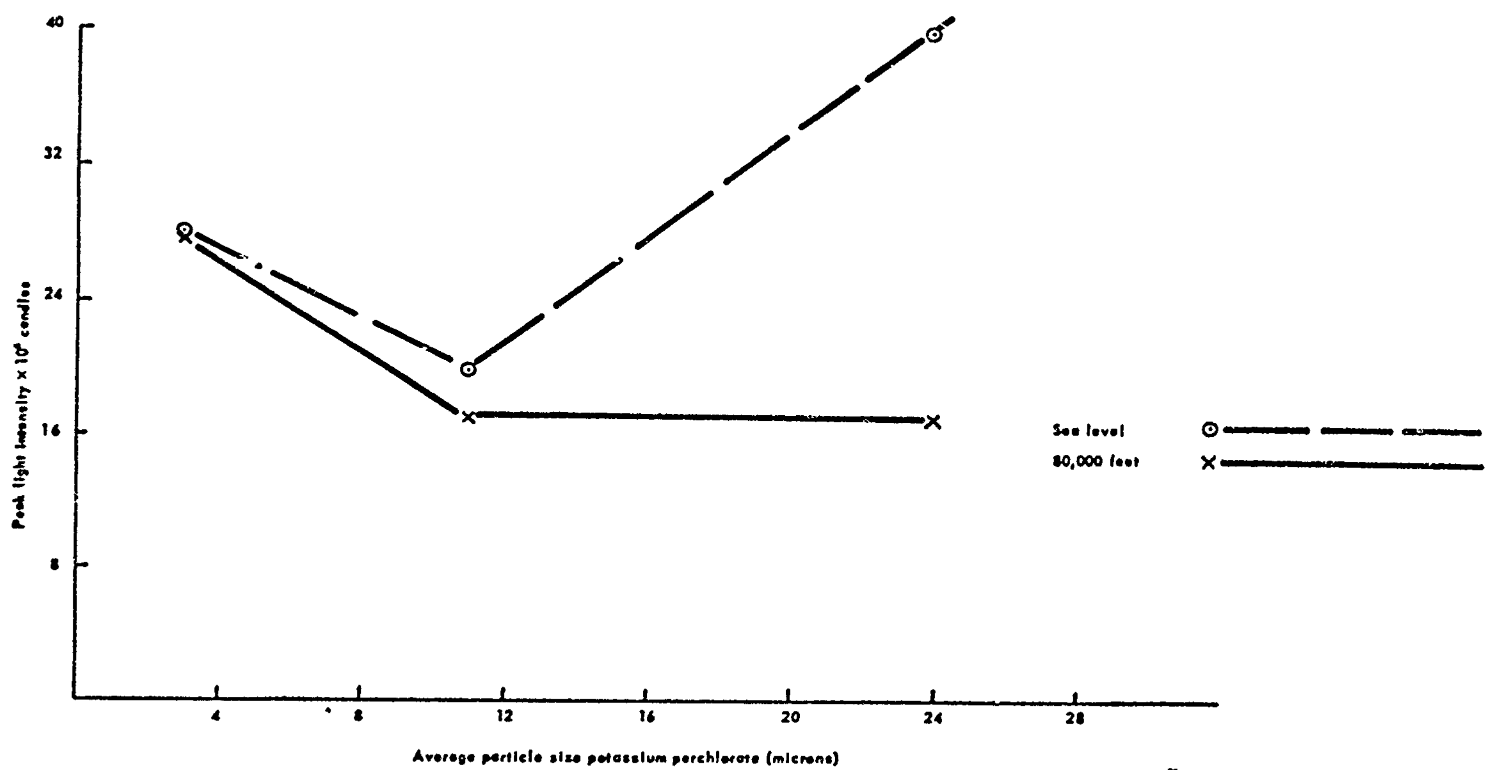

Fig 2 Effect of particle size of potassium perchlorate on peak light intensity of 60/40 potassium perchlorate/aluminum compositions (average aluminum particle size: 5.0 microns)

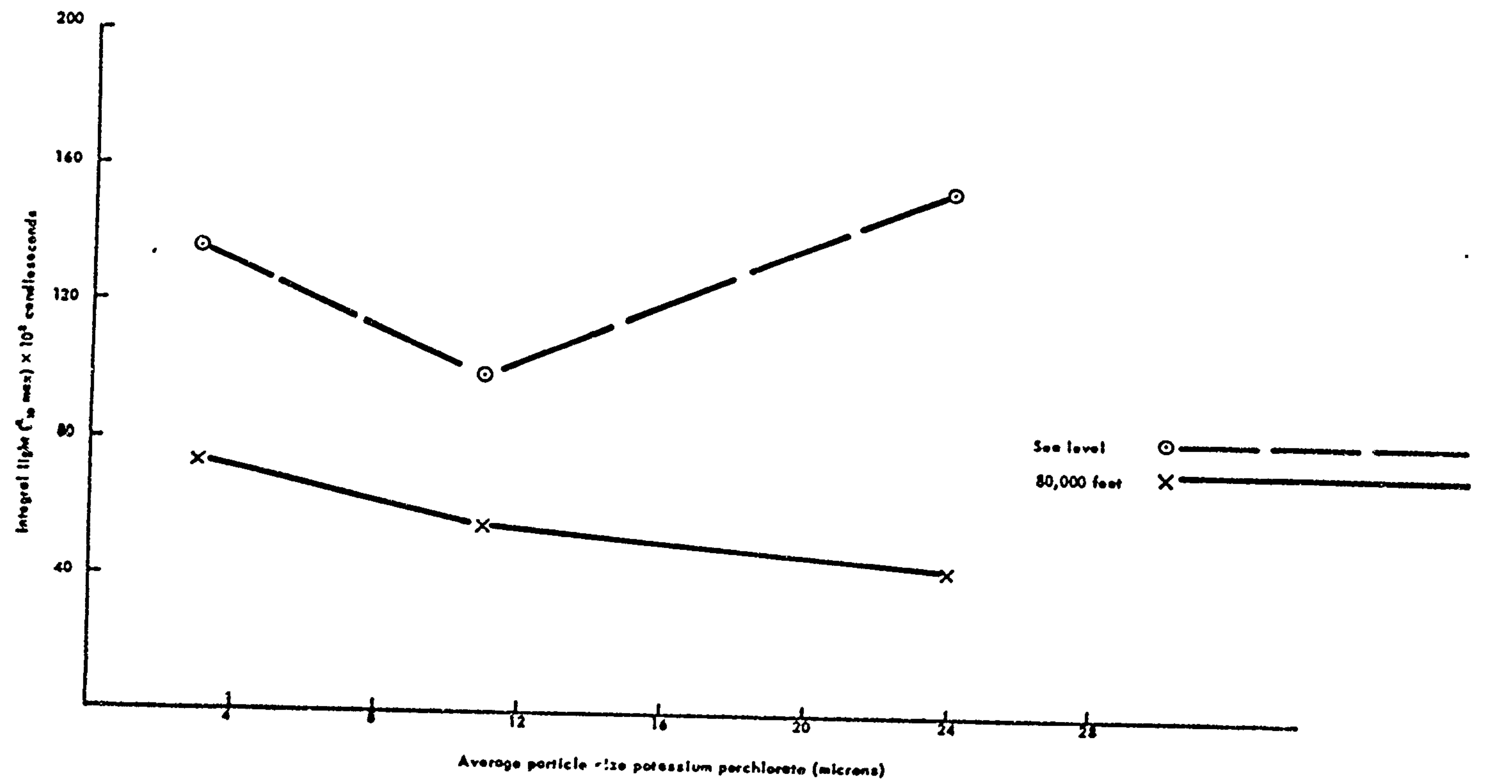

Fig 3 Effect of particle size of potassium perchlorate on integral light ($^1/_{10}$ max) of 60/40 potassium perchlorate/aluminum compositions (average aluminum particle size: 5.0 microns)

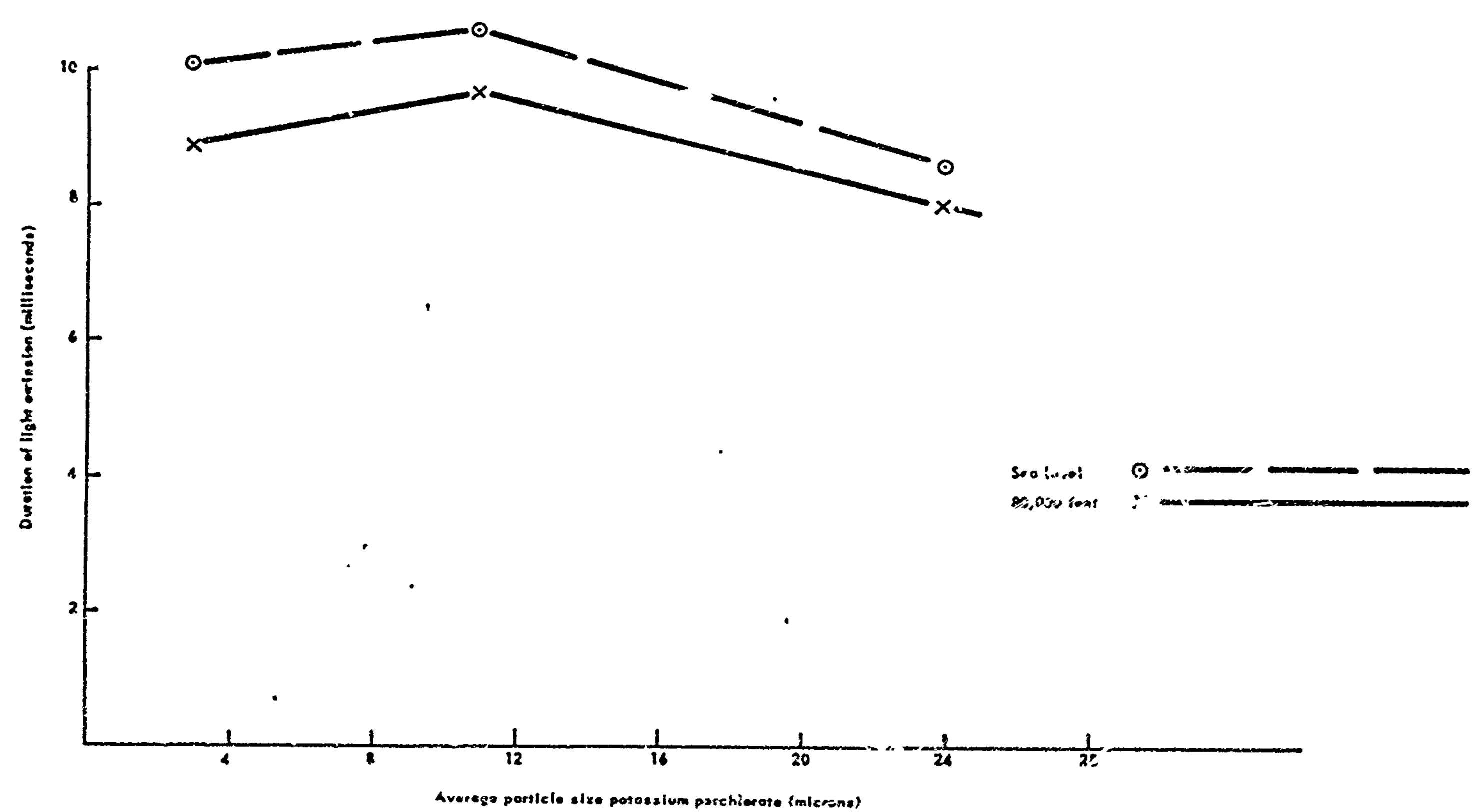

Fig 4 Effect of particle size of potassium perchlorate on duration of light emission (1/10 max) of 60/40 potassium perchlorate/aluminum compositions (average aluminum particle size: 5.0 microns)

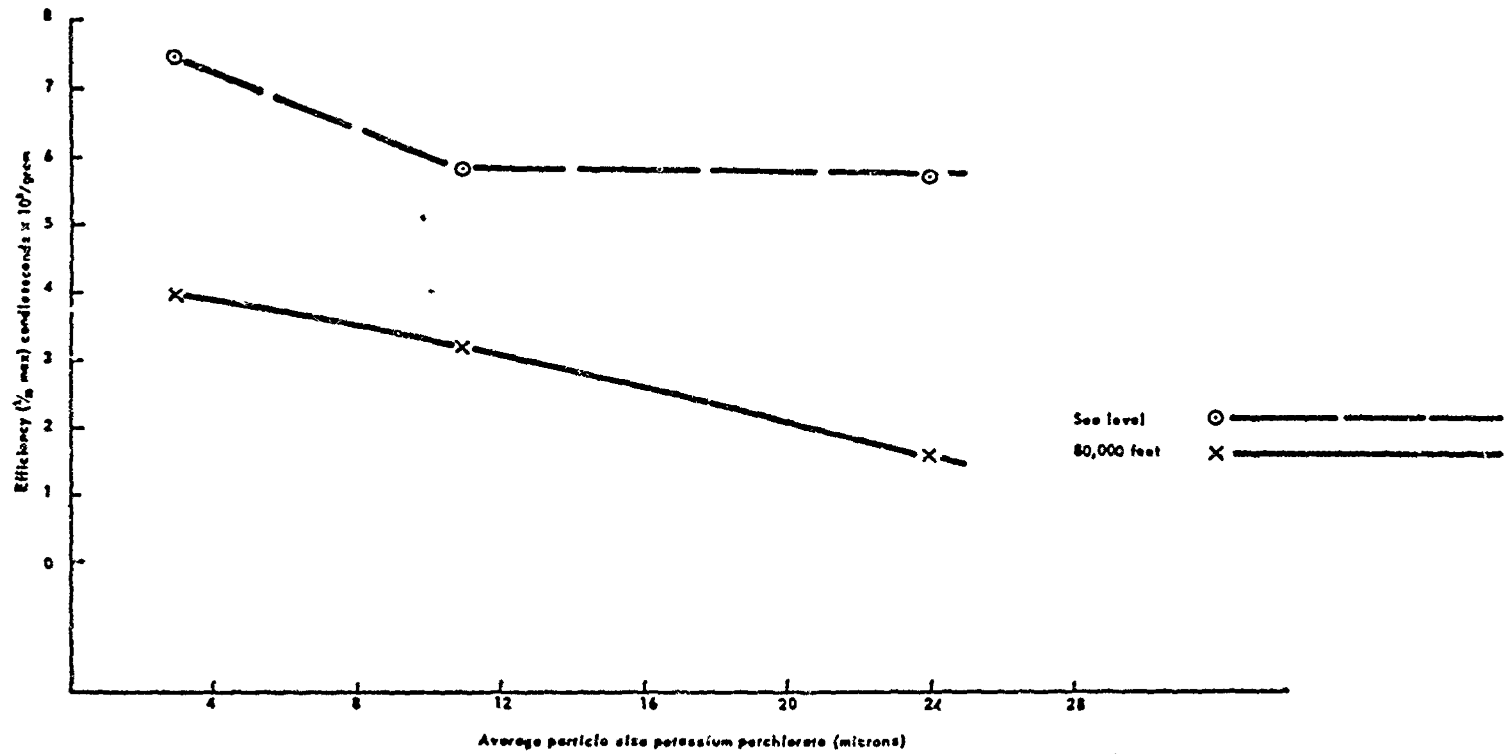

Fig 5 Effect of particle size of potassium perchlorate on luminous efficiency (1/10 max) of 60/40 potassium perchlorate/aluminum compositions (average aluminum particle size: 5.0 microns)

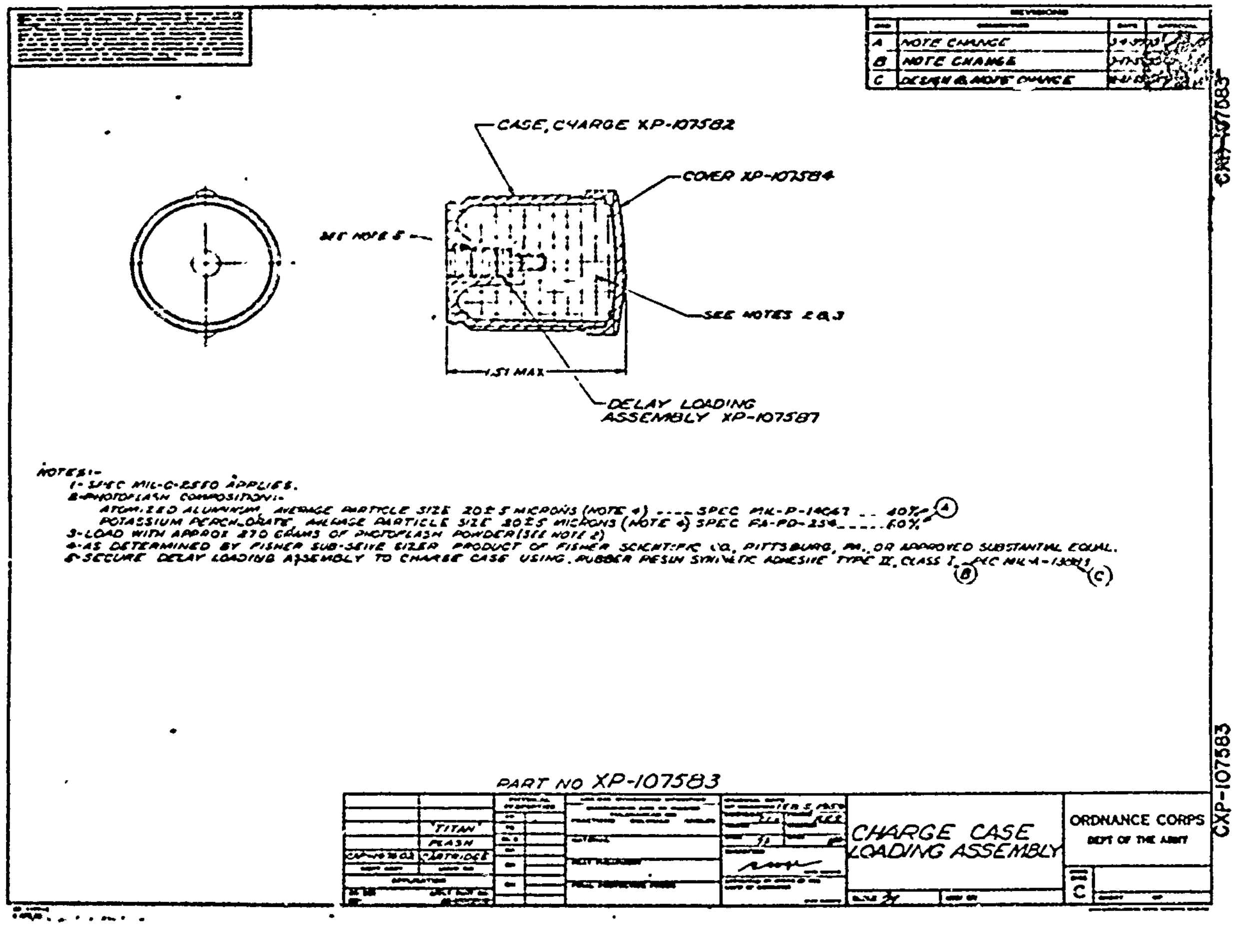

Fig 6 Charge Case Loading Assembly

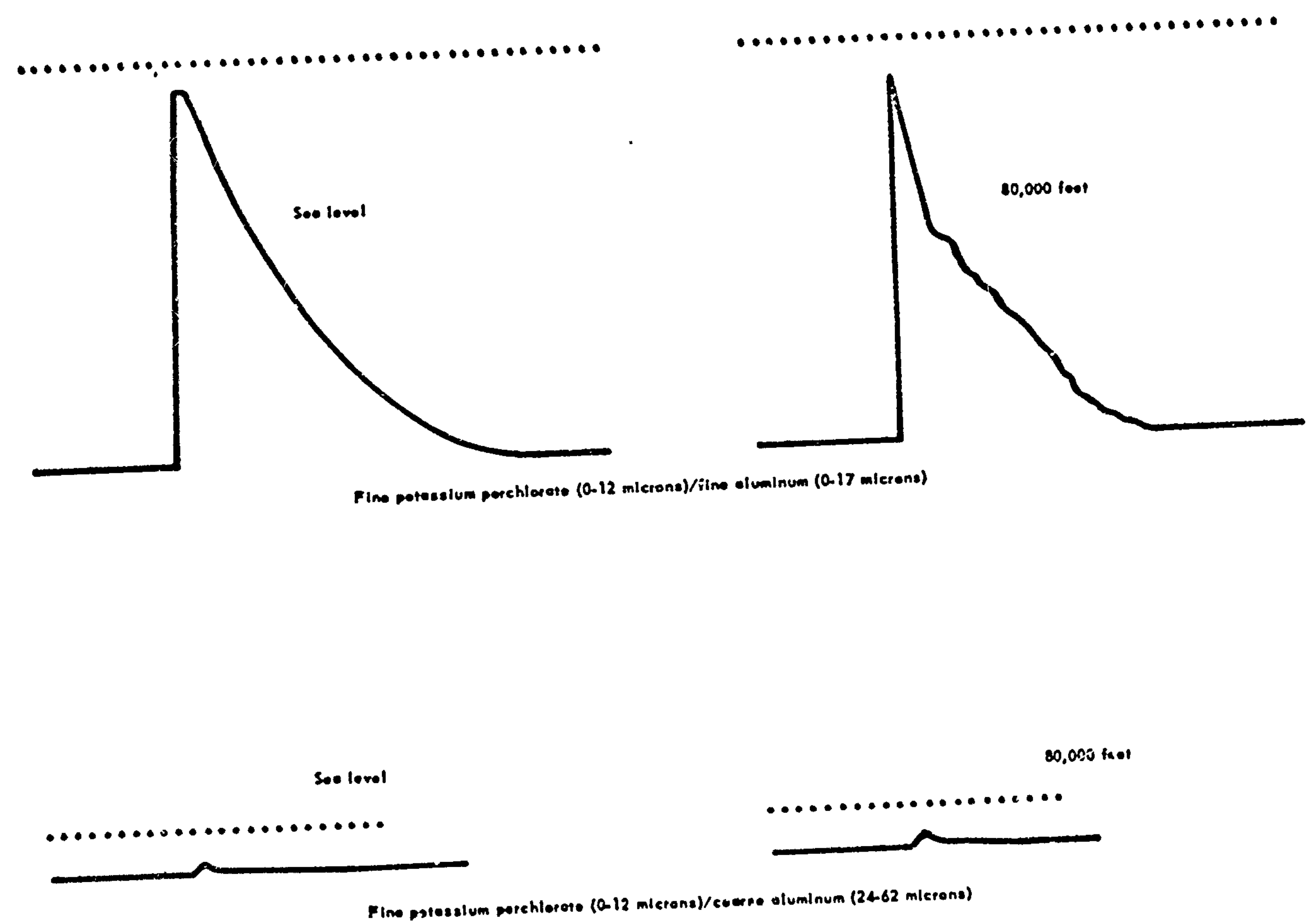

Fig 7 Time-intensity curves at sea level and simulated high altitude (60/40 potassium perchlorate/aluminum blends - 1st group)

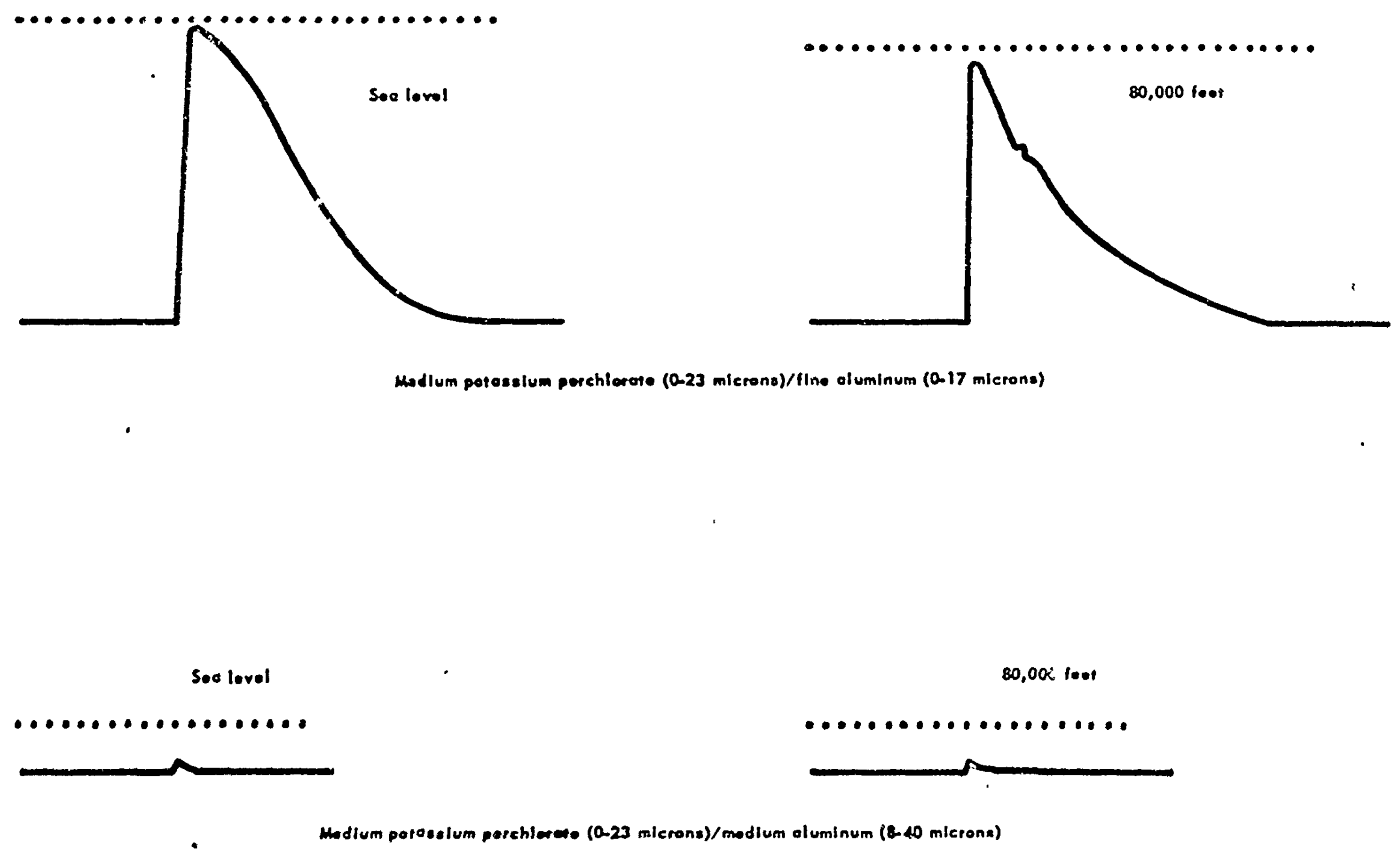

Fig 8 Time-intensity curves at sea level and simulated high altitude (60/40 potassium perchlorate/aluminum blends - 2nd group)

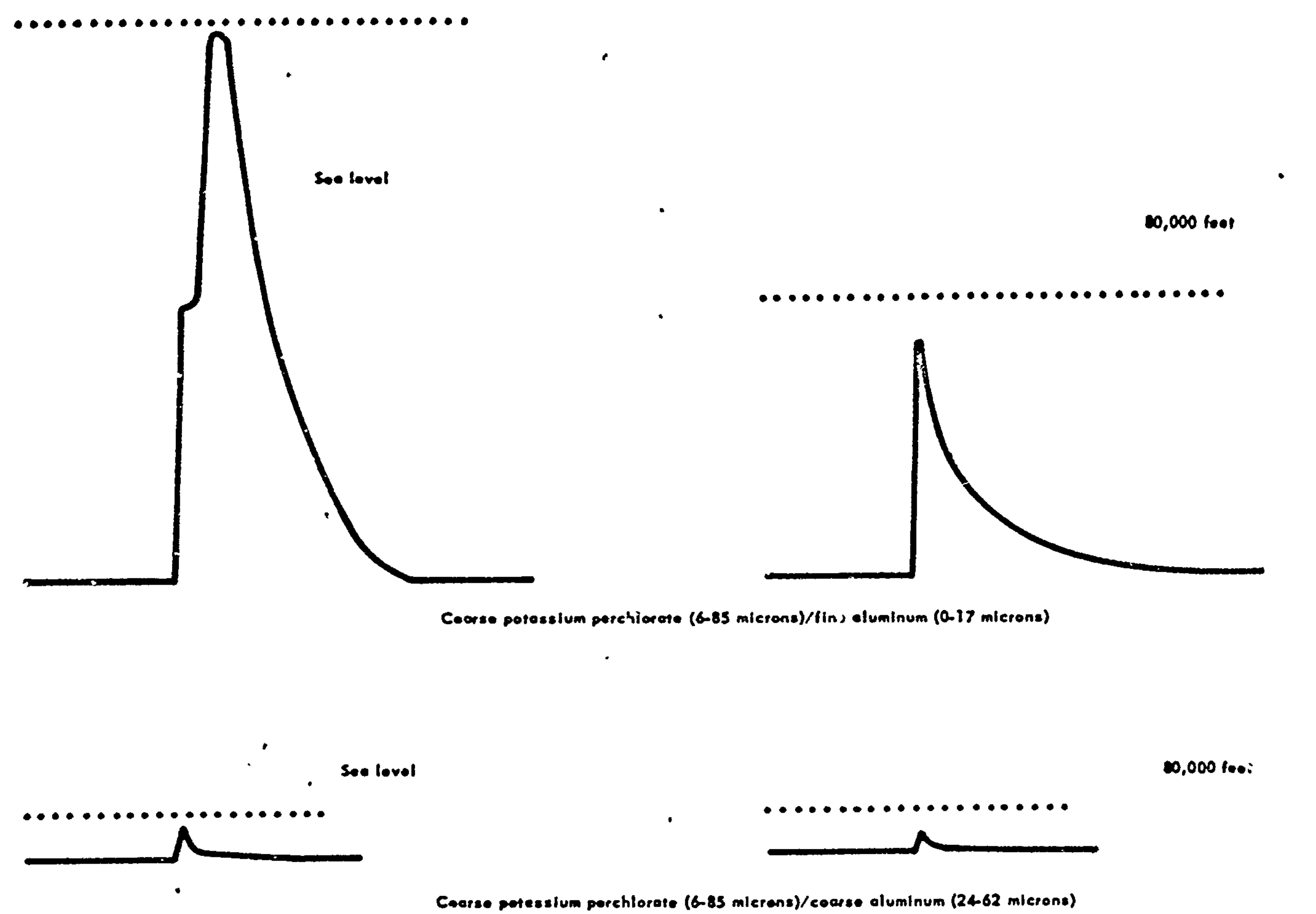

Fig 9 Time-intensity curves at sea level and simulated high altitude (60/40 potassium perchlorate/aluminum blends - 3rd group)

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EFFECT OF FUEL AND OXIDANT PARTICLE SIZE ON THE PERFORMANCE CHARACTERISTICS OF 60/40 POTASSIUM PERCHLORATE/ALUMINUM FLASH COMPOSITION

Seymour M. Kaye, Joel Harris

Technical Report FRL-TR-44, November 1961, 30 pp, tables, figures. DA Proj 504-01-027, OMS 5530.11.558A. Unclassified Report

Sub-sieve potassium perchlorate and atomized aluminum powders, commercially classified into fine, medium, and coarse fractions, were blended in 60/40 potassium perchlorate/aluminum compositions, loaded into plastic Titan cartridge cases, and tested for luminosity characteristics at sea level and a simulated altitude of 80,000 feet.

(over)

1. Pyrotechnics — Surface area
2. Pyrotechnics — Effectiveness
3. Aluminum powders — Combustion
4. Potassium perchlorate

I. Kaye, Seymour M.
II. Harris, Joel
III. OMS 5530.11.558A
IV. DA Proj 504-01-027

UNITERMS

Particle size
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Aluminum
Pyrotechnics
Luminosity
Kaye, S. M.

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Those systems containing fine (0-12 micron), medium (0-23 micron), and coarse (6-85 micron) potassium perchlorate together with fine aluminum (0-17 micron) were the only systems which emitted enough light for pyrotechnic applications. Maintaining the aluminum particle size constant (fine fraction) and decreasing the oxidant particle size increased efficiency (candleseconds/gram) at both sea level and 80,000 feet. In general, the peak and integral light varied similarly at high altitude. At sea level, however, the composition with the coarse oxidant fraction produced the highest peak and integral light. This finding was attributed to the greater tapped density of the coarse oxidant fraction, resulting in substantially greater sample weight in the Titan cartridge.

It was concluded that, independent of potassium perchlorate size range, use of medium (8.4-40 micron) or coarse (24-62 micron) aluminum degrades the light output to below useable levels. For the particle size ranges considered, use of a fine aluminum fraction is necessary for high order performance.

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